Interference Suppression using De-correlating Rake Receiver in case of WCDMA

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Abstract

Rake receivers are used for the detection of transmitted data in case of WCDMA communication systems due to its resistance to multipath fading. But rake receiver treat multiuser interference (MUI) as AWGN and have limitation in overcoming the effect of multiple access interference (MAI) when the SNR is high. A de-correlating matched filter has been used in this paper, which eliminates and improves system performance. Simulated results show a significant performance improvement for De-correlating RAKE receiver in terms of BER compared to a rake receiver. The performance of the de-correlating receiver for different spreading factor is also analysed.

Keywords:-WCDMA, de-correlating matched filter, rake receiver, MMSE.

I. INTRODUCTION

Wideband Code Division Multiple Access [1] (WCDMA) is one of the third generation wireless standard formed by (3GPP) third generation partnership project. It has wide band-width of about 5MHz and has an advantage of reduced fading and multipath diversity. It is used for various applications including wireless internet, video telephony and voice over IP.

Rake receivers are widely used as receiver in case of WCDMA systems. When the signal bandwidth is large and multipath components are delayed by a chip period, received signal can be treated as multiple copies of same signal, and can be combined constructively in rake receiver. This rake receiver overcomes the effect of multipath fading. When the spreading codes that are used for the spreading of the signal have good auto-correlation and cross-correlation property, i.e. auto-correlation is high and cross-correlation is as low as zero, rake receiver is able to overcome the effect of the multi-access interference (MAI) [2]. But practically in high data rate transmission through frequency selective channels, the signal loss orthogonality and hence, rake receiver performs poorly. The loss of the orthogonality has an adverse effect on both channel estimation and symbol detection and thus the performance degradation occurs when the system is heavily loaded i.e. when the number of users increases.

Rake receiver was first proposed by Prince and Green and patent in the year 1958 [3]. A blind two-dimensional Rake receiver for long-code CDMA was first proposed by Zoltowski et al. in [4] and was further developed. Their approach was the earliest blind multiuser detection method for long-code CDMA. Zoltowski's two-dimensional (2-D) rake uses a conventional matched filter as the first stage, followed by post processing to mitigate multiuser interference. A de-correlating matched filter is used in the paper [5] to separate users up front and perform single-user optimal Rake combining as the second step. The channel is estimated via a matrix pencil technique based on second-order statistics by Zoltowski et al. Here deterministic least squares is used, which has the advantage of requiring a small number of samples. Blind channel estimation and multiuser detection for long-code CDMA has been considered by a number of other authors [6]. Iterative techniques based on maximizing the likelihood function [7] and least squares [8] have been proposed. These methods have high performance but have the drawback of having high computational complexity.

In this paper channel estimation and symbol detection is performed using de-correlating rake receiver. The received symbol at the de-correlating matched filter front end is passed through the signal space of each user. After that the channel and data sequence can be estimated independent of other users by least square using rank one decomposition. The de-correlating matched filter does not depend on the channel coefficient. Here the scheme imposes no conditions on channel parameters and is thus capable of dealing with rapid multipath fading.

Following the introduction, the rest of the paper is organised as follows. Section II represents the system model of the WCDMA system. Section III describes the channel estimation method that is used and section IV presents simulation results i.e. the performance of the work. Finally section V gives the concluding remark.

II. SYSTEM MODEL

A CDMA based system model presented in [6] is considered here. Here an uplink application for K number of asynchronous users that are transmitting the modulated signal is considered. The signal is being transmitted in a number of slots where each slot comprises of M_k number of symbols i.e. $\{s_{km},\ m=1,2,\dots,M_k\}$ where 'k' is the k^{th} user. The spreading code C_{km} of gain G_k is multiplied with each symbol so that the signal that is transmitted is spreaded. The spreaded signal is passed through the channel having the channel weight h_{kj} {j $=1,\dots,L_k\}$, L_k being the length of finger for k^{th} user.

Here the received signal corresponding to the transmitted symbol s_{km} ,which is passed through a chip-matched filter h_{kj} and is sampled at the chip rate. After that we get the received samples as y_{km}. As shown in Figure. 1, y_{km} is a linear combination of shifted (delayed) code vector c_{km} , where c_{km} is the spreading code of G_k chips of user k's related to the m^{th} symbol. Each shifted code vector is multiplied by the j^{th} fading coefficient of h_{kj}, and the channel response to s_{km}, is given as

$$Y_{km} = T_{km} h_{kj} s_{km} \qquad (1)$$

Here $\boldsymbol{T_{km}}$ is the code matrix that is used by user k and symbol m, $\boldsymbol{h_k}$ is the multipath fading channel of user k. Each user has a delay of $\boldsymbol{D_k}$ chips with the reference. Each column of $\boldsymbol{T_{km}}$ corresponds to each multipath channel where the first column has $\boldsymbol{D_k}+(m-1)G_k$. zeros then the code and the rest space with zeros so that is forms the total number of chips of entire slot. The next column corresponds the next multipath channel and so on. The output can be given as

$$y_{km} = \sum_1^{M_k} \boldsymbol{T}_{km} h_k s_{km}$$

$$= \boldsymbol{T}_k(\boldsymbol{I}_{Mk} \otimes \boldsymbol{h}_k) s_k \qquad (2)$$

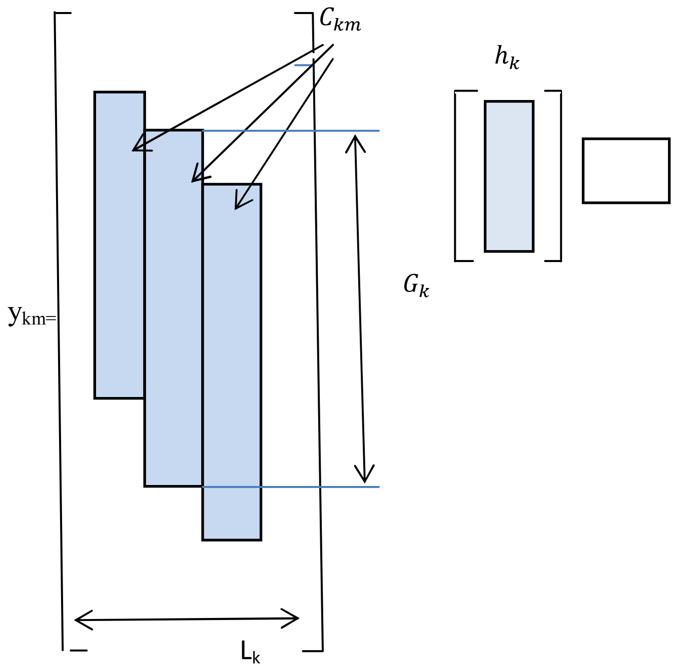

Figure 1 Code Matrix

Considering the noise (2) becomes,

$$\boldsymbol{y}=\boldsymbol{THs} + \boldsymbol{n} \qquad (3)$$

where, $\boldsymbol{T}$ is the code matrix and $\boldsymbol{H}$ is the knocker product of the identity matrix and the multipath channel weight h_k. The Knocker product is a large array formed by taking all possible product combination between identity matrix and channel weight. $\boldsymbol{s}$ is the signal that is being transmitted and $\boldsymbol{n}$ is the Gaussian noise.

It is assumed that receiver has the knowledge of the code and the delay. If delay is not known then it is considered to be zero.

III. BLIND DE-CORRELATING RAKE

A de-correlating rake receiver that estimates the channel as well as the symbol independently is presented in this section. The de-correlating matched filter uses $T^{\dagger}$ as the front end to remove multiple access interference. Here $T^{\dagger}$ is the Moore Penrose pseudo inverse of the code matrix T.

The output of the de-correlating receiver is given as

$$\boldsymbol{u} = \boldsymbol{T}^{\dagger}\boldsymbol{y}$$

$$= diag(\boldsymbol{I}\otimes\boldsymbol{h}_1, \boldsymbol{I}\otimes\boldsymbol{h}_2, \dots, \boldsymbol{I}\otimes\boldsymbol{h}_k)s + \boldsymbol{n} \qquad (4)$$

where $\boldsymbol{n}$ is the AWGN noise. The output is partitioned into blocks of L_k as

$$\boldsymbol{u}_{km} = \boldsymbol{h}_{\boldsymbol{k}} s_{km} + \boldsymbol{n} \quad (5)$$

where, s_{km} is the m^{th} transmitted symbol of k^{th} user and $\boldsymbol{h}_{\boldsymbol{k}}$ is the multipath fading channel of user *k*.

The channel and symbol can be estimated by

$$\boldsymbol{h}_k = argmax(g^H R_{km} g) \quad (6)$$

at $||g||=1$

$$s_{km} = \boldsymbol{h}_k^H \boldsymbol{u}_{km} \quad (7)$$

where

$$\boldsymbol{R}_{km} = \frac{1}{M_k} \sum_{m=1}^{M_k} \boldsymbol{u}_{km} \boldsymbol{u}_{km}^H \quad (8)$$

In places of blind channel estimation one can also use semi-blind channel estimation where the symbol that is transmitted is divided into the pilot and the data sequence.

The de-correlating front end works well in the absence of noise. But in the presence of noise it performance degrades. So a regularised de-correlating receiver or a MMSE is used that overcomes the effect of noise. The MMSE is given as

$$\boldsymbol{F} = (\boldsymbol{T}^H \boldsymbol{T} + \sigma^2 \boldsymbol{I})^{-1} \boldsymbol{T}^H \quad (9)$$

Such type of front end improves the performance at low SNR.

IV. RESULTS AND DISCUSSIONS

The simulated results are presented here for rake receiver, de-correlating rake and regularised rake receiver. In the simulation the spreading factor of {32 64} .The length of the finger that is used in WCDMA is 3. The channel weights were considered to be of minimum phase whose coefficient are {1 0.5 0.2}. At a time total 80 symbols were transmitted in each slot. Here we have used the BER as a parameter for the performance evaluation.

Figure.2 presents the result of BER vs. SNR for two users. At 10^{-3} we get an improved performance of about 2 dB compared to rake receiver. Figure.3 shows the performance for five users with a spreading factor of 32 and here we get a de-correlating receiver performance better than rake receiver which means even if the number of user increases then also we get a better result in de-correlating rake receiver compared to rake receiver. Similarly Figure 4 and Figure 5 shows the BER performance for two users and five users respectively for a spreading factor of 64. In the figure we find that as SNR increases rake receiver degrades while de-correlating rake receiver gives a better performance. The de-correlating rake receiver gives a better performance of about 2dB when number of user is 2 at 10^{-3} BER.

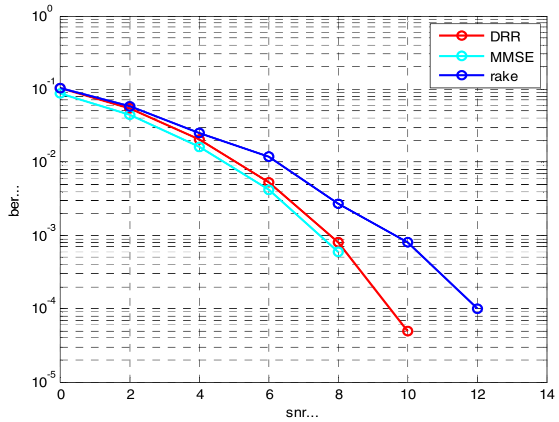

Figure 2.BER vs SNR for 2user in minimum phase channel at a SF of 32

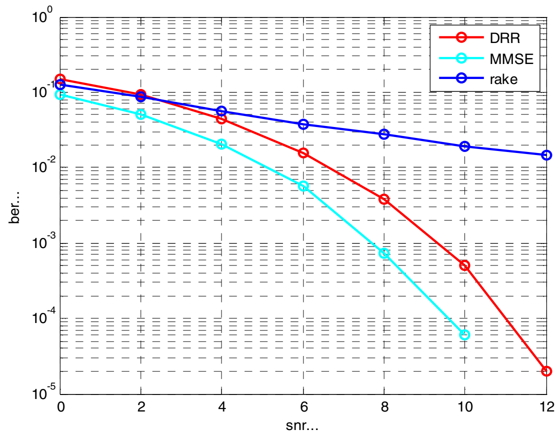

Figure 3.BER vs SNR for 5 user in minimun phase channel with a SF of 32

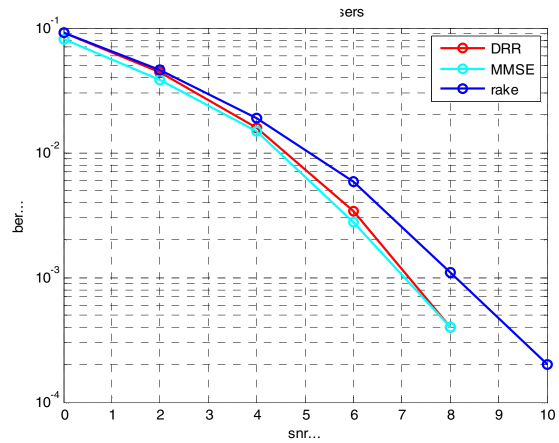

Figure 4.BER vs SNR for 2 user in minimum phase channel at a SF of 64

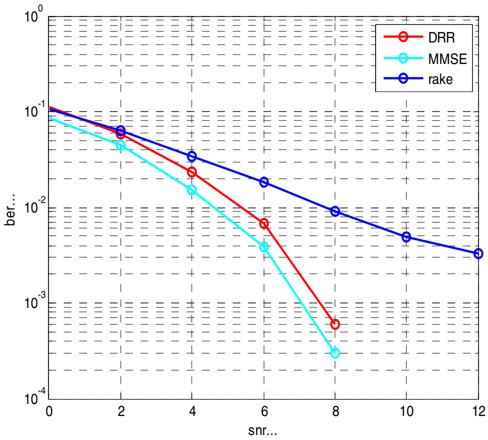

Figure 5.BER vs SNR for 5 users in minimum phase channel at a SF of 64

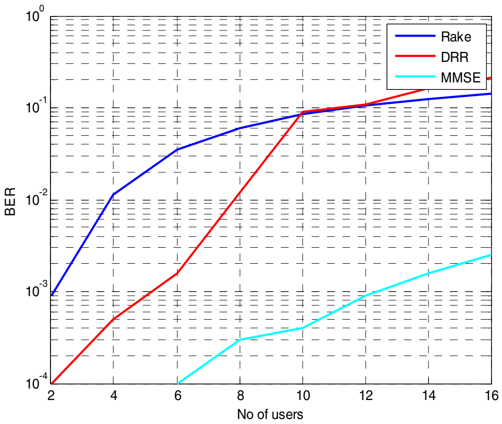

Figure 6 BER vs Number of user at SNR of 10dB

Figure.6 shows the graph of BER verses the number of users at 10dB SNR. Here we found that as the number of user increases the probability of computing the error decreases but in case of MMSE the error is less compared to the other two techniques. The de-correlating receiver saturates after 10 users for a spreading factor of 32.

V. CONCLUSION

In this paper, the problem of channel estimation and multiuser detection for long-code WCDMA systems operating over frequency- selective fading channels has been considered. Here a blind channel estimation and symbol detection algorithm was used. Here we find that performance in terms of BER in de-correlating rake receiver is better compared to the conventional rake receiver. The de-correlating receiver performs well in the absence of noise, but in the presence of noise with more number of users MMSE linear equaliser gives much better results.

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